ICBEN review of research on the biological effects of noise 2011-2014

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ICBEN review of research on the biological effects of noise 2011-2014

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Abstract

The mandate of the International Commission on Biological Effects of Noise (ICBEN) is to promote a high level of scientific research concerning all aspects of noise-induced effects on human beings and animals. In this review, ICBEN team chairs and co-chairs summarize relevant findings, publications, developments, and policies related to the biological effects of noise, with a focus on the period 2011-2014 and for the following topics: Noise-induced hearing loss; nonauditory effects of noise; effects of noise on performance and behavior; effects of noise on sleep; community response to noise; and interactions with other agents and contextual factors. Occupational settings and transport have been identified as the most prominent sources of noise that affect health. These reviews demonstrate that noise is a prevalent and often underestimated threat for both auditory and nonauditory health and that strategies for the prevention of noise and its associated negative health consequences are needed to promote public health.

Keywords: *Annoyance, health, hearing loss, noise, performance, pollution, sleep*

Noise-Induced Hearing Loss

Introduction

Noise is one of the most prevalent environmental and occupational hazards, which, if excessive, may cause hearing damage. According to the recent estimation of environmental noise pollution, as many as 104 million individuals in the US had annual $L_{EX,24h}$ levels of above 70 dB in 2013, and were at increased risk of noise-induced hearing loss, heart diseases, and other noise-related health effects.[1] The extrapolation of this data could suggest that noise-related health problems may be affecting one-third of the global population.[2]

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This section of the paper focuses on achievements in research on noise-induced hearing loss (NIHL) and noise-induced tinnitus (NIT) from the last 3 years. Almost 700 papers published between 2011 and 2013 were identified by a literature search of accessible medical and other databases (including PubMed, Embase, Scopus, Biomed Central, and Web of Science). The most important new findings are presented by topic and target group in this overview.

Prevalence of NIHL and NIT

Interesting results were obtained from the National Health and Nutrition Examination Survey. Based on this survey, a study found that the prevalence of NIHL in the unscreened population of US adults aged 20-69 years was almost 13%

in 2013. Odds of NIHL were significantly increased for older people, males, and smokers.[3]

The risk factors for NIHL relating to different kinds of noise were further characterized for over 4,500 inhabitants of New York City by collecting survey data. It was shown that when using the American National Standards Institute (ANSI) algorithm S3.44-1996 at 4000 Hz, a greater number of individuals was at risk of NIHL from MP3 players and stereos, although risk for the greatest NIHL was for those with high occupational and episodic nonoccupational exposures.[4]

Taking into account a high rate of environmental exposures among teenagers and young adults, much attention was paid to the prevalence of NIHL and NIT in the younger groups of subjects. Although no significant increase in NIHL was observed, the rate of noise-induced threshold shift was significantly higher in adolescents with high exposure to music[5] and in young females.[6] The latter finding may reflect the increased exposures of young women to recreational noise.

Alarming data have emerged from a study on the prevalence of tinnitus. Permanent NIT was reported by almost 15% of university students in the Netherlands, with higher incidence in female subjects, and in 18% of high school students.[7,8] Although audiometric thresholds did not differ significantly between veterans and nonveterans for most high frequencies, the overall prevalence of tinnitus was significantly greater in veterans than in nonveterans, confirming its relationship with previous exposures to noise.[9]

Occupational exposures

Despite the widespread implementation of hearing conservation programs over recent decades, NIHL continues to occur in industrial settings. Studies have shown that about 22 million US citizens, who account for about 7% of the entire national population, are exposed to hazardous noise at the workplace. The analyses of audiograms performed in the years 2000-2008 of male and female workers aged 18-65 years, who had higher occupational noise exposures than the general population, showed that the actual prevalence of occupation-related hearing loss was at 18%. The highest risk for hearing loss was observed for the mining and wood products industry (27.0%), followed by building and real estate construction workers (23.5%).[10]

Among the industries with elevated exposures to noise, special attention was paid to the construction industry. A retrospective analysis of NIHL performed in almost 30,000 Dutch workers showed greater hearing losses compared to their nonexposed colleagues as well as compared to the reference population reported in the International Standards Organization (ISO) model ISO-1999.[11] The relationship between exposure time and hearing loss followed the ISO-1999 prediction when considering a timespan of 10 years or longer. A 10-year prospective study including over 300 US construction workers confirmed that this group is at risk of NIHL.[12] Noise exposure was estimated at 87 dB(A). A significant exposure-related elevation in hearing thresholds was about 2-3 dB over the projected 10-year period at 3 kHz, 4 kHz, and 6 kHz for 10 dB increase in exposure.[13] An important finding of this investigation was that task-based exposure estimates had much greater variability than did trade-mean-equivalent continuous exposure levels. This should be taken into account in risk assessment and the development of hearing conservation programs for construction workers.[12]

Several studies published over the last 3 years focused on the dose-response relationship for occupational hearing loss and establishing or reestablishing the measures of risk assessment. The comparison of different metrics for tracking occupational hearing loss in aluminum industry workers showed that at least two methods — namely, a 10 dB, age-corrected threshold shift from baseline and a 15 dB, non-age-corrected shift metric — correlated well with the difference between observed and expected high-frequency hearing loss. These measures were proposed to be recognized as an international standard.[14]

New findings related to the contribution of MP3 player use at work to overall occupational noise exposure surfaced from recent studies. The data of 24 workers listening to music through such devices at the workplace showed that their effect might be significant, predominantly in individuals working against low background noise.[15] More studies on this topic and on larger populations should be performed to formulate hearing protection recommendations.

Entertainment/music industry

Entertainment/music industry workers constitute a special category of employees at risk of developing occupational hearing loss. While in most industries occupational noise is an unwanted by-product of the technological processes, in the entertainment industry "noise" is the desired product. That is why for many years this sector was not controlled by legislation.

In response to growing scientific evidence for the increased prevalence of hearing loss in professional musicians and nightclub workers, the European Union (EU) Directive 2003/10/EC introduced regulation of noise protection in the entertainment sector. According to the regulation, employers ranging from orchestras to nightclubs are legally required to adhere to the same requirements as those in other industries. However, the entertainment industry is failing to meet this European regulation.[16]

Personal dosimetry completed in musicians during 2-h rehearsals and 4-h performances confirmed earlier observations that they are at high risk of developing NIHL. Time-weighted average sound values ranged 84-96.4 dB(A) for rehearsal and 91-102.8 dB(A) for performance, greatly exceeding allowable limits.[17] Moreover, solitary practice, performed on average 2 h per day at the levels of 60-107 dB, L_{Aeq}, was found to increase the risk of hearing loss in as many as 53% of musicians.[18]

Further evidence for this case comes from a study conducted with 47 individuals of metropolitan Seoul. Measurements were taken with personal noise dosimeters and showed that the traditional Korean music apprentices had the highest value of average $L_{eq,24h}$ estimate, that is, 89 dB(A), surpassing heavy equipment operators, firefighters, and other professionals.[19]

Despite extremely high exposures to sounds, the use of hearing protection in musicians is very low. It was shown that only 18% of horn players, who constitute the highest-risk group among orchestral musicians, reported the use of hearing protection. A majority of them (81%) used hearing protectors only occasionally.[20]

As for the nightclubs, the average Irish pub employee's daily noise exposure ($L_{\mathrm{EX,8h}}$) was estimated at 92 dB(A), almost four times higher than the accepted legal limit. None of the clubs considered for evaluation in this study were compliant with the EU Directive 2003/10/EC regulation.[21]

All the studies cited above indicate an increasing necessity for introducing hearing conservation programs in the entertainment industry, even though audiometric data published recently for musicians are not alarming.[22]

Nonoccupational exposures

Leisure activities

The first study considered here analyzed five leisure activities. These were: Attending:

1. Nightclubs;
2. Pubs and clubs;
3. Fitness classes;
4. Live sporting events; and
5. Concerts and live music venues.

Among these, the nightclubs were shown to be the main source of high-risk leisure noise.[23] Exposure levels in these venues were measured, and survey data for 1,000 Australian young adults were referred to.[24] When using population-weighted metrics, a majority of study participants were noted to have had exposures within the acceptable workplace noise limit. However, 14% were overexposed, and those exposed to more leisure noise experienced more tinnitus. The authors recommended that nightclub operators reduce noise levels, display warnings, and provide earplugs for patrons and employees.[24] Alarming data about health effects emerged from a study conducted with 300 British students. As many as 88% of subjects experienced tinnitus after leaving a nightclub and 66% suffered temporarily impaired hearing the following morning. Although over 70% felt that the noise at the nightclub should be limited to safe levels, a similar percentage of study subjects claimed that they would attend clubs despite the risk of hearing loss.[25]

Although nightclub attendance poses the greatest risk of hearing loss, the highest prevalence of permanent hearing loss among teenagers and young adolescents was found in students studying popular music. The results from the audiometric data for young British musicians showed the audiometric notch at 4-6 kHz in almost half of them (47%). Moreover, 16% of the individuals were classified under the UK Occupational Health and Safety guidelines as exhibiting mild hearing loss.[26] Despite risky behavior, the use of hearing protectors is low in teenagers, and was estimated at only 3% in females and 10% in males.[6]

Personal music players (PMPs)

Nowadays, as many as 88-90% of teenagers and young adults report listening to music through earphones on personal music players (PMPs).[27,28] Even though the time of their use represents only a small fraction of the total annual hours for each subject on average, they are the primary source of overexposure among the majority of urban residents and workers.[29]

A large number of papers published over the years 2011-2013 estimated the risk of hearing loss due to the use of PMPs, as well as the actual incidence of hearing loss and tinnitus in exposed populations. The studies were carried out in, among others, American, Canadian, Dutch, Italian, Israeli, Chilean, Brazilian, and Malaysian teenagers and young adults.[27,28,30-36]

The maximum sound pressure level of the PMPs through in-ear earphones reached 126 dB, with a 14.4 dB difference depending on the style of music.[34] This level seems to be substantially higher than previously reported in the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) report (120 dBSPL).[37] Mean preferred listening levels (L_{eq}) varied widely within the range 68-86 dB(A), depending on the population, background noise, type of music, and method of measurement. Self-reported mean daily use ranged 0.014-12 h.[32]

Under worst-case listening conditions, the percentage of teenagers and young adults at risk of developing NIHL was estimated to be between 17% and almost 29% (17% in the USA, 18% in Chile, 22.4% in Canada, 27.4% in Italy, and 28.6% in the Netherlands). Even though these numbers were calculated using different approaches and noise limits, they are substantially higher compared to the estimation of the SCENIHR report (5-10% of the population at risk of developing NIHL).[37]

The actual incidence of hearing loss and tinnitus in teenagers and young adults using MP3 players was also evaluated. Hearing loss of ≥25 dB at one or more frequencies was found in 7.3% among 177 Malaysian PMP users.[36] In Brazilian teenagers, the incidence of tinnitus in nonusers was about 8%, while in PMP users it was about 28%, and this difference was statistically significant. The incidence of tinnitus was associated with higher hearing thresholds at 8 kHz.[35]

To conclude, an increasing number of teenagers using PMPs at high or very high volume settings for several hours a day may result in an increased prevalence of NIHL later in the lives of today's younger generation.

Clinical research

There is growing evidence that noise can be harmful not only to the cochlea, but also to some parts of the peripheral vestibular organ, the saccule. A statistically significant correlation was found between high-frequency hearing loss and saccular dysfunction in older individuals.[38] Furthermore, severe NIHL can contribute to fall risk in the elderly population.[39,40]

As pure-tone audiometry may not detect early signs of cochlear damage caused by noise, other tests were used to screen and monitor NIHL. Effort was exerted to optimize distortion-product otoacoustic emission (DPOAE) for tracking noise-exposed subjects longitudinally.[41] Although the first observation in construction workers was promising in the aspect of the higher sensitivity of DPOAE (mainly at 4 kHz) in monitoring early signs of NIHL, a 10-year prospective study showed no advantage of this method over standard audiometry.[13] One of the limitations of translating the data is that significant individual otoacoustic emission (OAE) changes do not necessarily follow the same pattern as the group-averaged results. Moreover, hearing deterioration might manifest itself in a local enhancement of OAE.[42]

As for screening of occupational NIHL, using speech in noise tests proves very promising.[43] High sensitivity and specificity to detect high-frequency hearing loss were found for the digit triplet test.[44] More studies in this field are needed.

Basic research

The most interesting research in animals was regarding the processes that underlie the generation of tinnitus after overexposure to noise. It was shown that tinnitus was related to the hyperactivity in the central auditory pathway occurring after cochlear damage.[45] Moreover, excessive (neuropathic) noise exposure may lead to defects of the ribbon between inner hair cells (IHCs) and spiral ganglion neurons, and to subsequent gradual auditory nerve degeneration.[46] IHC ribbon loss (deafferentation) and nonadaptive brain response (central neural excitability) following acoustic trauma may lead to tinnitus.[47-49] Another animal study confirmed that despite the full recovery of hair cell function after exposure to noise, there was still a loss of up to 30% of auditory-nerve synapses in guinea pigs.[50] However, the damage was selective only to fibers with low spontaneous rates. The selective loss of these high-threshold fibers would explain how adaptive brain response (ABR) thresholds can recover after acute noise trauma despite significant noise-induced neuropathy. It has been hypothesized that this selective loss of high-threshold fibers contributes to the problems of hearing in noisy environments.[50]

The results of human study seem to be in line with those from the animal research, as it was shown that in rock musicians after band practice, transient tinnitus was accompanied by increased gamma activity in the right cortex. The authors concluded that noise trauma leads to increased neural synchrony in the auditory cortex and explained that the right-side cortex laterality is due to more pronounced hearing loss in the left ear.[51]

In the years 2011-2013, several studies on the pharmacological protection of hearing after acoustic trauma were performed in animals and humans. The results confirmed the promising protective effects of D-methionine,[52-55] and of a combination of antioxidants.[56]

The current knowledge of gene polymorphism underlying an increased susceptibility to NIHL in humans was summarized.[57]

Prevention

A novel technology that allows workers to record noise exposures inside hearing protectors on a daily basis was tested.[58] Daily monitoring of at-ear noise and regular feedback on exposures from supervisors apparently reduced the risk of occupational NIHL.[59]

New devices for noise protection were tested to suit the needs of most emerging groups, such as musicians and PMP users. Electronic earplugs (active hearing protection) for orchestral musicians were developed. These devices deliver very high-quality sound and attenuate only when sound levels become excessive. Musicians preferred the devices to previous earplugs, although they still identified issues with the new devices, they identified issues including difficulty with orchestral balance, perception of dynamics, and quality of sound provided by the devices.[60] Attention was paid to the use of noise-cancelling headphones to reduce the hearing hazard for PMP users.[61] It was shown that in the presence of ambient noise, the preferred listening levels obtained from noise-cancelling headphones were reduced by up to 4 dB, compared to conventional earbuds.[62]

The studies published in the years 2011-2013 confirmed in principle earlier observations that the effectiveness of educational intervention for NIHL prevention may be of limited effectiveness and short-lasting.[63] Moreover, no correlation was found between acquired knowledge and behaviors regarding the use of hearing protection, nor was any correlation found between NIHL in exposed and nonexposed individuals.[64]

Conclusion

The studies published in the last 3 years indicate an emerging necessity of introducing hearing conservation programs in the entertainment industry. It can also be concluded that the risk of developing NIHL from PMP use in an increasing population may lead to an increased prevalence of NIHL later in the lives of today's younger generation. Technological progress in developing new-generation headphones for PMP users is lacking.

Nonauditory Effects of Noise

Introduction

ICBEN Team 3 covers the nonauditory, physiological, cardiovascular, and mental health effects as well as the effects on birth outcomes, of environmental and occupational noise. It is well known that noise exposure can lead to adverse health effects.[2,65,66] A wide range of noise effects was already known (or at least hypothesized) in the 1960s. Since then, a large number of experimental and observational studies have been carried out to further refine these insights. After the adoption of the EU Environmental Noise Directive (END) in 2002, an increasing number of large epidemiological studies focusing on cardiovascular disease (CVD) have been conducted around the world. Prominent cardiovascular health end points studied include myocardial infarction (MI) and hypertension.

In 2011, The Environmental Burden of Disease (EBoDE) Working Group conducted a project in six European countries. In this study the disability-adjusted life-years (DALYs) due to nine selected environmental stressors, including transportation noise, were estimated.[67] Traffic noise was among the top three stressors with the highest estimated overall public health impact. DALYs due to traffic noise exposure were estimated to be in the same order of magnitude as DALYs due to passive smoking, with particulate matter (PM) of air pollution showing the highest impact. Although the main burden of disease due to traffic noise was imposed by sleep disturbance/disorder, CVD was estimated to cause remarkable morbidity and premature mortality. These studies on the burden of disease underline the importance of environmental noise effects as a public health problem.

For this review, the literature published during the period from August 2011 to December 2013 was searched. Sixty peer-reviewed journal publications were identified,[68-127] which indicated that an impressive amount of progress in the field was made during the last 3 years. Many results were published based on data analyses of existing or ongoing cohort studies. The combined effects of noise and air pollution were investigated by an increasing number of studies over recent years. The identified literature and a selection of important findings are introduced here.

Road traffic noise

Cardiovascular effects due to road traffic noise have been studied intensively over many years. In 2012, a meta-analysis was carried out based on 24 studies on road traffic noise exposure and the prevalence of hypertension to derive an exposure-response relationship. An odds ratio of 1.034 [95% confidence interval (CI): 1.011-1.056] per 5 dB increase in $L_{Aeq,16h}$ was found within the range 45-74 dB.[68] A threshold value could not be derived from this analysis.

An association between road traffic noise exposure and incidence of diabetes was reported based on analysis of the Danish Diet, Cancer and Health cohort, with an adjusted incidence rate ratio for confirmed diabetes of 1.14 (1.06-1.22) per 10 dB in L_{den}.[69] The author noted that the mechanism between noise exposure and incidence of diabetes was assumed by a number of studies of the effects of excess cortisol and sleep disturbances. Analyses of data of this same cohort also revealed a significant association between road traffic noise exposure and MI.[70]

The association between road traffic noise exposure and blood pressure was investigated in a number of cross-sectional studies among children[71-74] and among pregnant women.[75]

Furthermore, a laboratory study was published recently that investigated road traffic noise-related changes in blood pressure and in cardiac and hemodynamic parameters.[128] In 2014, a meta-analysis was published with an updated exposure-response relationship for road traffic noise and coronary heart disease (CHD).[129]

Noise and air pollution from road traffic

In recent years, an increasing number of studies on the combined effects of noise and air pollution have been published,[76-87] including a first systematic review.[76] The systematic review[76] concluded that studies available to date suggest that confounding of cardiovascular effects by noise or air pollutants is low, and that these insights may change with further improvements in exposure assessment in future studies. More recent studies[78,80] also seem to support the independence of the effects of noise and air pollution on CVD.

In a large Canadian cohort study ($n = 445{,}868$), the association between long-term exposure to community noise and air pollution, and mortality from CHD was investigated.[78] A 10 dB (L_{den}) increase in community noise level was associated with an increase in the risk of death from CHD [relative risk (RR) 1.09; 95% CI 1.01-1.18], after adjustment for sex, age, preexisting comorbidity, socioeconomic status (SES), and air pollution. Data analyses on a large cohort study in the Netherlands (n = 18,213) did not reveal a significant association between hospital admission and ischemic heart disease (IHD) or CVD after adjustment for potential confounders including air pollution.[79]

The association between road traffic noise, air pollution, and atherosclerosis {using a measure of subclinical atherosclerosis [thoracic aortic calcification (TAC)]} was investigated in a cross-sectional study.[80] $PM_{2.5}$ and L_{night} were both found to be independently associated with an increase in TAC. No remarkable confounding was found between $PM_{2.5}$ and L_{night}, which would support the hypothesis of the independent effects of noise and air pollution.

The combined effect of road traffic noise and air pollution on blood pressure was also investigated in a number of cross-sectional epidemiological studies[81-83] and in a field experiment.[84] These studies, however, showed inconsistent results. In the Danish cohort, the association between air pollution mortality from CVD[85] and hypertension[86] was studied, with adjustment for traffic noise. A prospective study[87] was also conducted on the association between incident MI and change in traffic exposure.

Aircraft noise

The majority of studies on the cardiovascular effects of aircraft noise have focused on blood pressure and hypertension. In the last 3 years, two large-scale studies were conducted focusing on the association between aircraft noise exposure and CVD, CHD, or stroke in the UK[88] and the US.[89]

In the UK, the association between aircraft noise exposure and the risk of hospital admission and mortality for stroke, CHD, and CVD were assessed around Heathrow airport.[88,90,91] During the 2001-2005 period, 189,226 first episodes of hospital stay for CVD and 48,347 deaths occurred in the studied area. Significant increases in risk of admission with increasing aircraft noise exposure were reported for stroke, CHD, and CVD, after adjustment for potential confounders, including road traffic noise and air pollution. Similar significant associations were also found for mortality from stroke, CHD, and CVD.

A retrospective study of approximately 6 million older people was conducted around 89 airports in the US based on the billing claims against the national insurance program for the year 2009.[89] The association between aircraft noise (L_{dn}) and hospital admission rate for CVD was studied based on zip code, with adjustment for potential confounders including air pollution and road traffic noise. Across all airports, aircraft noise exposure was associated with the hospital admission rate of CVD, with a 3.5% (CI: 0.2-7.0%) increase per 10 dB.

Noise from multiple traffic sources

Combined effects of transportation noise (from different source types) were investigated in several studies, using traffic noise maps (road, railway, and aircraft), which have become available in many countries during recent years. Four studies[92-95] focused on railway noise. However, inconsistent results related to train noise were found for blood pressure or CVD among the studies.

A cross-sectional study in six European countries showed an association between nighttime aircraft noise, and heart disease and stroke.[96] This result was robust after adjustment for air pollution in the subsample (three countries) analysis. The association between 24-h average road traffic noise level, and heart disease and stroke was also significant, although the association was not adjusted for air pollution.

An association between breast cancer and traffic noise was reported based on analyses of data from the Danish cohort of about 30,000 women.[95] Road traffic, railway, and aircraft noise were assessed. In the subsample of estrogen receptor-negative breast cancer, exposure to both road traffic and railway noise is associated with a higher risk of breast cancer. It was hypothesized that this association (if causal) may be explained by a decrease in immune strength due to sleep disturbance.

Other studies on environmental noise

A systematic review paper[97] focused on the association between noise exposure during pregnancy or childhood and health outcomes in early or late childhood. Studies on a range of health outcomes such as birth weight, preterm birth, blood pressure, and stress hormone levels were included in this review.[98] The authors concluded that from the investigated literature, there seemed to be no evidence at the time of review, for an association between chronic noise exposure and pregnancy outcomes from studies which were categorized as "highest evidence level 2+", while there was some evidence supporting an association with systolic blood pressure and stress hormone levels.[99]

Quality of life (QOL) is an important subjective measure of health status from the viewpoint of the definition of health in the WHO constitution. Several studies[100-103] were carried out and targeted at associations between road traffic noise and wind turbine noise exposure and QOL, using a standardized questionnaire.

Occupational noise

The associations between occupational noise, and hypertension and stroke were investigated based on a large cohort study, although no significant association was detected.[104,105] However, other studies[106-109] reported a significant increase in risk of hypertension with increasing noise exposure.

Based on a cohort study in Taiwan, the association between occupational noise exposure and the development of hypertension was investigated considering angiotensin (AGT) gene polymorphisms.[106] The risk of hypertension in workers with the TT genotype increased with noise exposure, which revealed a potentially vulnerable group for noise exposure.

The joint effect of job strain and exposure to road traffic noise and occupational noise on MI was investigated in a cross-sectional study.[110] Analyses revealed that exposure to a combination of noise and job strain increases the risk of MI. In addition, a longitudinal study was performed which, after adjustment for a broad range of cardiovascular health factors (e.g., blood pressure, fasting serum triglyceride, and cholesterol), did not find an association between occupational noise exposure and death from IHD.[127]

Experimental studies

To investigate the physiological mechanism through which noise exposure may lead to CVD and hypertension, laboratory studies[111,112] and field studies[84,113-117] were carried out, with a variety of outcomes. Three studies[111-113] focused on noise and vibration during nighttime. One study[114] was carried out for 24 h. Other studies[84,115-117] investigated the effects of daytime noise. There is sufficient evidence for a relationship between insufficient sleep and changes in metabolic and endocrine functions, which in the long term may lead to CVD and hypertension. However, a recent review on the effects of occupation noise concluded that the mechanism for chronic effects of occupational noise seems to remain unclear.[118]

Future research needs

Some "new" outcomes were studied for the potential long-term health effects of traffic noise. They included diabetes,[69] breast cancer,[95] hypotension,[119,130] and Alzheimer's disease.[120] The hypothesized mechanism for the development of these effects include insufficient sleep, but further research is needed to investigate these relationships, and to confirm the hypothesized causation.

Measurement of noise sensitivity may aid epidemiological studies, as higher noise effects may be found in vulnerable groups.[121] One recent study[106] demonstrated that the risk of hypertension in workers with a specific genotype increased with noise exposure, which suggested that noise sensitivity as a host factor could be correlated with various health conditions.[122,123]

Some studies indicated that annoyance caused by traffic noise was a modifier of the association between noise level and health.[124,125] However, this correlation should be interpreted with caution. Individual noise exposure largely depends on housing conditions and lifestyle,[126] and an equivalent sound level (e.g., L_{night}) was chosen for mainly practical reasons.[65] Annoyance might act as a supporting variable in the regression model to compensate for the defect of the noise exposure level on façade. More consistent results may be obtained with a more appropriate noise index and with adjustment for housing conditions and lifestyle.

Effects of Noise on Performance and Behavior

Introduction

Team 4 of the International Commission of the Biological Effects of Noise takes as its concern the effects of noise on performance and behavior. The team members mainly include psychologists, cognitive ergonomics specialists, and acousticians who through joint resources study the basic principles of why people are distracted by noise, and how noise effects become manifest in applied settings such as offices, schools, hospitals, and dwellings.

Overview of recent research findings

In this part of the paper, we outline recent research divided into two thematic sections: One that centers on basic research questions and one applied section (offices and schools).

Basic research

The role of cognitive control in auditory distraction has been a central topic of investigation during the past 3 years.[131,132] Some of this research has used task difficulty manipulations to delineate how cognitive control processes facilitate selective attention. In a study by Sörqvist, Stenfelt, and Rönnberg,[133] participants were requested to undertake an easy or a difficult version of the *n*-back task (wherein the participants view a sequence of letters and their task is to respond to each new item and indicate if a particular new item is the same as the item presented *n* steps back in the sequence) while they were also being presented with a to-be-ignored background sound. The neural processing of the sound, as shown in auditory brainstem potentials, was attenuated when the visual task was difficult (i.e., 3-back) in comparison with when it was easy (i.e., 1-back). This suggests that there is a trade-off between visual-verbal task demands and the extent to which irrelevant sound is processed. Moreover, the difference between the 3-back and the 1-back condition was larger in individuals with high working memory capacity (WMC, a measure of general cognitive control capacity).

Some of this research has used cognitive control manipulations as a tool to study the functional similarity/dissimilarity between the changing-state effect and the deviation effect. Background sound that changes perceptually (e.g., the sound sequence "k l m v r q c") is more disruptive to serial short-term memory than sound that does not change (e.g., the sequence "m m m m m m m"), and this is the changing-state effect. A sound sequence that contains a single element that deviates markedly from the rest (e.g., the sequence "c c c m c c c"), is also more disruptive to serial short-term memory than a nonchanging sequence, and this is the deviation effect. In a recent set of experiments, Hughes, Hurlstone, Marsh, Vachon, and Jones[134] requested that participants immediately recall sequences of visually-presented items that were either masked by visual noise (but still perceivable) or presented without visual noise. The visual-noise manipulation attenuated the deviation effect, but not the changing-state effect. Based on these results, the authors argued that the two effects are functionally different: The deviation effect is a result of attention capture, which can be overruled by increasing the need to focus on the target information in the visual modality, whereas the changing-state effect is a result of involuntary sequential processing of the background sound that comes into conflict with the deliberate act of sequentially reproducing the visually-presented items.

A recent meta-analysis of individual difference studies found further support for the general conclusion that the changing-state and the deviation effect are manifestations of two functionally different forms of distraction.[135] Specifically, the meta-analysis found that individual differences in WMC are related to individual differences in susceptibility to the deviation effect but not to the changing-state effect. Taken together, these studies suggest that the deviation effect, a result of sound diverting attention away from the focal task, can be overruled by cognitive control (e.g., by engaging more with the visual task and thereby reaching a more steadfast locus of attention), whereas the changing-state effect cannot be overruled by cognitive control. However, a new set of studies on habituation speak to the functional similarity between the two effects.[136,137] Habituation, the process whereby the disruptive effect of noise decreases as familiarity with the noise increases, is arguably a result of an attenuated orienting response, as habituation to the changing-state effect seems to occur.[136,137] This effect also seems, just as the deviation effect does, to be a consequence of attention capture.

Applied research

Some of this research has aimed to bridge recent basic research with an applied setting by borrowing the idea of a trade-off between task engagement and distractibility. For instance, it has been shown that the potentially disruptive effects of background speech on proofreading[138] and memory of written prose[139] only becomes manifest when the text is written in an easy-to-read font. When the text is displayed in a hard-to-read font, there is no disruptive effect of noise. One interpretation of these findings is that higher task difficulty promotes a more steadfast locus of attention, in comparison with lower task difficulty, in which instances the sound's ability to grab attention is attenuated. This is consistent with the notion that the deviation effect disappears when to-be-recalled items are masked by visual noise,[134] and with the notion that neural responsiveness to a background sound attenuates when the visual task is more difficult.[132] These results have clear applied implications: Intellectual work in noisy environments (such as a classroom filled with children's babble) might benefit from manipulations that make the focal material more difficult to perceive.

Another line of applied research concerns the evaluation of standing acoustic guidelines for open-plan offices. One objective predictor that is used to evaluate the acoustic environment is the Speech Transmission Index (STI). STI is a physical measure of speech intelligibility and is standardized by the International Electrotechnical Commission (IEC) as IEC 60268-16. It ranges from perfect speech intelligibility (i.e., 1.00) to no intelligibility at all (i.e., 0.00) and depends mostly on signal-to-noise ratio, reverberation, and the amount of early reflections between the source and the receiver. STI is proposed to be a predictor of how much performance is reduced due to background speech depending of its intelligibility.[140] Therefore, it is assumed that reduction of STI will provide relief from cognitive disturbance. However, STI also captures aspects of the temporal-spectral variability of background speech, which does not necessarily go along with intelligibility. This idea becomes clearly evident when thinking about foreign speech, which might be unintelligible to the listener but incorporates temporal-spectral variability. Temporal-spectral variability of background sound is known to be a key feature for the changing-state effect to arise. Partial masking (i.e., superimposing ambient speech with another sound signal/masker) has been identified as a possible countermeasure to reduce the negative impact of background speech, as it is capable of reducing both the intelligibility and the temporal-spectral variability of background speech. It has been shown that maskers differ in their ability to shield against the effects of cognitive performance and annoyance.[141,142]

The types of tasks that have been used to investigate the influence of background speech in open-plan office settings have often been rather unrepresentative for typical office-related work.[143] The qualities that make speech special — such as the fact that it has semantic meaning — in comparison with other types of sound (e.g., noise from a printer) only enhance the disruptive nature of background speech when a task requires the processing of meaning.[144] Thus, the use of unrepresentative tasks may lead to the drastically underestimation of the disruptive effects of low STI values, especially as office-type tasks often require the processing of meaning (e.g., word-processed writing). In recent attempts to study the effects of varying STI levels on more representative tasks, such as reading, mental arithmetic, and information searching, impairments were found at lower levels of STI than the current acoustical guidelines suggest.[145] In another set of experiments using word-processed writing, which is a task highly representative of office work, disruptive effects of background speech were found, whereas no disruptive effect was found in the case of a meaningless sound that was acoustically very similar to ordinary speech.[144] In a follow-up experiment, a more detailed analysis of the disruptive effects of speech was used and a marked performance drop in word-processed writing was found; the STI value of the background speech reached above 0.23.[146] However, other psychoacoustical measures have also been discussed to better predict the disturbance impact of background sound.[147]

A third line of applied research concerns the effects of noise on performance in the school environment. For example, memory[148] and comprehension[149] of spoken messages are impaired by low signal-to-noise ratio (and long reverberation), but these effects tend to be smaller for those individuals who can compensate for the disruption, either by high WMC[148,150] or by knowledge structures in long-term memory.[149]

Another line of research (the AkuLite and AcuWood projects) has focused on noise annoyance caused by walking noise in multistory timber buildings. The goal was to find technical descriptors that correlate well with the human perception of walking sound. It has long been known that the correlation between standardized evaluation methods (e.g., using the tapping machine) and the human perception of impact noise on lightweight floor constructions can be poor. Measurements and recordings on different types of floor constructions, equipped with different floor coverings were performed in the laboratory. In addition, field measurements of both single- and multifamily multistory houses were made, covering a wide range of modern lightweight floor constructions. Different technical and real sound sources were employed. In this database, listening tests with subjective ratings of the walking noises were correlated with single-number physical descriptors. The results show that the frequency range of technical measurements has to be extended to the low-frequency domain (20-50 Hz) in order to capture the annoyance perception of test subjects and other residents. Annoyance reactions were described by a percentage of annoyed persons.[151] Acoustical requirements based on the percentage of annoyed persons seem to be more easily understood by builders, clients, lawyers, politicians, and other people involved in the building process, even without acoustical knowledge.

Future research needs

Applied research has typically used noise manipulations that do not isolate the manifestation of the changing-state effect and the deviation effect. One target for future research is to bridge the basic research findings with applied ambitions, by studying how a sound's acoustic features (e.g., variability) influence performance on applied tasks (e.g., reading comprehension) rather than serial short-term memory. Additionally, the suitability of the STI as a set value for the design of open-plan offices needs to be clarified. The STI approach has limitations that might be addressed by organizational measures in workspaces. Also, the application of psychological methods within technical standardization should be extended to bridge the gap between the technical and human sciences.

Effects of Noise on Sleep

Introduction

A range of sleep disturbance effects has been observed among persons who have lived in noisy areas for many decades. Exposure to noise during sleep causes acute effects, such as awakenings, difficulties in falling asleep, and sleep stage changes as well as a decrease in subjective sleep quality. Acute and chronic sleep restriction or fragmentation have been shown to affect waking psychomotor performance, memory consolidation, creativity, risk-taking behavior, signal-detection performance, and risks of accidents.[2,152] In 2011, the WHO regional office for Europe reported on the burden of disease in terms of DALYs lost due to environmental noise.[2] The findings suggest that sleep disturbance, due mainly to road traffic noise, constitutes the heaviest burden followed by annoyance; they account for 903,000 and 587,000 DALYs, respectively.

In the experimental or observational study context, one typically investigates the night noise effects on such outcomes as signalled awakenings, actigraphy parameters, cardiovascular arousals, or alterations of EEG patterns (e.g., awakening reactions); on global sleep parameters such as self-reported sleep disturbances; on total sleep time (TST), sleep efficiency (SE), or wake after sleep onset (WASO); or on hormonal parameters (e.g., cortisol secretion). Each has its own advantages and disadvantages, and its own definition of disturbed sleep. In a recent paper on the issue,[153] the merits and drawbacks of five established methods commonly used for the assessment of noise effects on sleep (polysomnography, actigraphy, electrocardiography, behaviorally confirmed awakenings, and questionnaires) were discussed, and the authors concluded that a consensus on a standard measurement technique for the assessment of environmental noise effects on sleep would be desirable to foster comparability of future studies. Another recent method paper was devoted to sample size estimation for field studies on the effects of aircraft noise on polysomnographically determined awakening reactions.[154]

Evidence has increased in the last decade that noise events elicit awakenings and autonomic responses at relatively low exposure levels and with different types of sources and in different study environments (field and laboratory). The evidence for noise effects on global sleep parameters — with the exception of self-reported sleep disturbances[155] — is less clear, as are the effects of noise on (next-day) hormonal parameters (e.g., morning cortisol). Many of the observed effects are not specific for noise, and are in general less severe than, e.g., those observed in clinical sleep disorders.[156]

One peculiarity that makes it difficult to determine clear exposure-response relationships for autonomic and cortical responses to noise is that they also occur naturally in the absence of noise or any other obvious external triggers. Signs are getting stronger that despite observable cortical reactions to noise events, there is, within limits, some homeostatic mechanism for internal monitoring and control of waking arousals (or maintaining sleep). A puzzling finding from a laboratory study reported by Basner *et al*.[157] was that most (>90%) of the noise-induced awakenings merely replaced awakenings that would have occurred spontaneously.

The differences in noise-induced sleep disturbance due to different transportation modes have been the subject of considerable debate in the last few years. Several laboratory and field studies challenged the so-called "railway bonus," by showing that railway noise events during sleep elicit stronger bodily reactions than aircraft or road traffic noise events.[157-159] The usually rather short rise times of the sound level of railway events were identified as one important characteristic of railway noise that is responsible for the effect.

It has been clearly established that subcortical noise-induced arousals basically do not habituate, or do so to a much lesser degree than cortical arousals and awakenings.[157,160] To date, the challenging — and basically unresolved — question has been how to establish an acceptable point at which acute reactions to noise result in clear negative health end points in the long run.[161] Currently, the preferred hypothesis is that nonhabituating autonomic reactions to noise events such as heart rate or blood pressure increases might be the most important category of precursors of long-term cardiovascular outcomes.

Recent research findings

The last 3 years have seen continued interest in both acute and short-term effects of noise on sleep in observational settings, as well as in epidemiological studies that focused on long-term health impacts of night noise exposure. In the following paragraphs, we will briefly report on the most recent findings, source by source.

Road traffic

A recent German study investigated road traffic noise exposure at home, and child behavioral problems and sleep disturbances.[162] The study included 872 children aged 10 years from Munich from two German population-based, birth-cohort studies with data on modelled façade noise levels at home. The researchers found that noise exposure levels at the least exposed façade were related to more emotional symptoms, whereas noise at the most exposed façade was related to more hyperactivity symptoms. Nocturnal noise at the least exposed façade was significantly associated with sleeping problems.

A Belgian questionnaire survey within the framework of the EU QSide project provided evidence that the presence of a quiet façade at a dwelling can reduce noise annoyance and sleep disturbances.[163]

Results from a diary study in Basel, Switzerland shed some light on the mediating role of road traffic noise annoyance in the genesis of sleep disturbances, concluding that effects of nocturnal traffic noise on sleep efficiency, measured with actigraphy, are independent of noise annoyance, whereas self-reported sleep quality was strongly related to noise annoyance but only moderately correlated with noise exposure.[164] Strikingly, in this study, noise-induced decreased sleep efficiency was even more significant for study participants who were not annoyed by road traffic noise.

Railways

With the ongoing extension of railway transport facilities, railway noise effects have received increasing attention in the past 3 years. The German Aerospace Center investigated sleep disturbances in 33 polysomnographically measured subjects living alongside railway tracks[159] and concluded that during nighttime, a bonus for railway noise seems unjustifiable, as nocturnal freight train noise exposure was associated with increased awakening probabilities exceeding those observed with aircraft noise.

A French research team studied the effects of nocturnal railway noise experienced at home on waking EEG and cognitive performance in persons who had been living for longer than 10 years either near a railway track or in a quiet environment.[165] Their results showed that reaction time was significantly delayed in the near-railway dwellers compared to the quiet-environment group. The authors suggest that permanent exposure to nocturnal railway noise deteriorates cognitive performance, reflecting chronic sleep debt in subjects living alongside railway tracks.

Specific to the railway transport is the fact that it often also creates vibrations in the dwellings of nearby residents. Lack of knowledge in this area encouraged a group from the University of Gothenburg, Sweden to experimentally investigate the impact of increasing the vibration amplitude of freight trains on self-reported sleep disturbance and heart rate in the sleep laboratory.[112,166] They exerted horizontal vibrational force with a shaker mounted beneath the bed frame, and found a decrease in latency of cardiovascular arousals and an increase in amplitude of heart rate, as well as a reduction in self-reported sleep quality, resulting from increasing vibration levels and unchanged noise exposure levels.

Aircraft

A team led by Frank Schmidt at the Johannes Gutenberg University in Mainz, Germany recently carried out a blinded experimental field study on 75 healthy volunteers, and investigated the effects of simulated aircraft noise on endothelial dysfunction and stress hormone release during sleep.[113] The subjects were not habitually exposed to aircraft noise. The researchers found that acute nighttime aircraft noise exposure dose-dependently impairs endothelial function and stimulates adrenaline release. They concluded that noise-induced endothelial dysfunction may in part be due to increased production of reactive oxygen species and may thus be one mechanism contributing to the observed association of noise exposure with CVD in the long run.

In a recent Journal of the Acoustical Society (JASA) paper, Fidell *et al*.[167] developed the idea that the probability of (behavioral) awakening due to aircraft noise is more closely related to exposure metrics that are scaled in units of standard deviations of the location-specific distributions of aircraft noise exposure levels, than to absolute sound levels. This reflects the importance of different communities and their "tolerance" (due to self-selection and habituation effects) toward noise. This concept, which was in a similar way also postulated for annoyance earlier and by the same group of authors,[168] has attracted considerable controversy and still awaits proof of its value for noise policy.

Wind turbines

As a consequence of the substantial growth of wind energy facilities everywhere in the world, scientists and policy makers have increasingly focused on the environmental impact of these facilities over the last few years. This growing interest has also been reflected in several recent publications in the Noise and Health Journal, some of which also focused on sleep disturbances.[169,170] Several studies on the effects of wind turbine noise have been carried out recently, with particularly strong research activities in Scandinavia and in the Netherlands. In the Netherlands, Bakker *et al*.[171] investigated the relationship between exposure to the sound of wind turbines and self-reported sleep quality using a questionnaire that was sent to a representative sample of residents. The authors found that wind turbine sound exposure was related to sleep disturbance and psychological distress among those who reported that they could hear the sound, but only with noise annoyance acting as a mediator. No direct effects of wind turbine noise on sleep disturbance could be found.

Hospitals

There has been continuing interest in the negative health effects of noise on patient rehabilitation in hospitals, especially concerning sleep disturbances, with sleep disruption being the most common noise-related patient complaint.[172,173] A recently published laboratory study on 12 healthy adult subjects developed sleep arousal probability threshold curves for 14 sounds typically encountered in hospital environments.[174] The most disturbing sounds were alarms and ringing phones. A recent Swedish study[175] aimed to explore whether patient sleep could be improved by modifying the sound environment in a way that is practically feasible in intensive care units, but failed to demonstrate a significant effect of reduced maximum sound pressure levels — from 64 dB(A) to 56 dB(A) — on sleep. Also, new evidence has been reported that moderate acoustic changes can disrupt the sleep of neonates in their incubators.[176]

Other noise sources

A few studies dealing with more "special" noise sources and their impact on sleep have also appeared in recent years, such as the work of Vos and Houben, who presented a re-analysis of data gathered from a study that investigated signalled awakening effects from shooting and civil impulse sounds[177] and found that multiple impulse sounds (e.g., shooting sounds appearing in a volley) induced higher awakening rates at the same overall sound exposure level than did single impulse sounds such as aircraft landings. A Swiss field study investigated 27 subjects living in the vicinity of churches that ring bells during the night, using polysomnography, and extrapolated the awakening effect to a larger population in the greater Zurich area.[178] The authors concluded that the sleep-disturbing impact of nocturnal church bell noise should not be neglected, as church bells ringing during the night is a common occurrence in many countries around the world.

Future research needs and outlook

While the association between nighttime noise and health outcomes can clearly be demonstrated, the specific causal chain between reactions to individual noise events in the night and the long term (e.g., cardiovascular) outcomes is not yet fully understood. For instance, the question of how many noise-induced awakenings, cardiovascular arousals, or the like, should or could be "allowed" to prevent negative health consequences from a public health point of view is difficult to answer as long as it remains unknown how the occurrences of primary reactions to noise relate to long-term health effects (and whether such primary reactions have a significant long-term effect at all). Elucidation of the mechanism by which noise-disturbed sleep leads to significant reduction in health is therefore a primary goal to reach. It can be hypothesized that chronic (noise-induced) sleep disturbances result in an increased cardiometabolic morbidity and mortality risk. These associations, however, are likely to be modified by individual genetic and health predispositions as well as by subjective evaluations of noise, different attitudes, and different coping strategies applied to evade the noise.[161] The fact remains that the interpretation and implication of the effect of noise sensitivity on sleep would possibly be aided by a better understanding of the individual factors that discriminate between good and bad sleepers. Two large ongoing studies that both combine observational, experimental or quasi-experimental, and large population-based epidemiological branches such as the Noise-Related Annoyance, Cognition, and Health study (Project NORAH)[179,180] in Germany, or the Short and Long Term Effects of Traffic Noise Exposure study (Project SiRENE)[181] in Switzerland, will hopefully shed new light on these important questions. The SiRENE study will probably be the first of its kind to systematically elucidate the role of the *PER3* circadian clock gene in carriers of the 4/4 and 5/5 variable number tandem repeat (VNTR) polymorphism in noise-induced sleep disturbances. Results from these studies are expected to become available in the next few years.

Concerning the quantification of noise-induced sleep disturbances, we suspect that the measurement of subcortical, basically autonomous (e.g., cardiovascular) arousals instead of cortical arousals will become more important; in parallel, the further development and use of simplified methods to measure sleep disturbances in field settings will probably also gather momentum.

Community Response to Noise

Introduction

The "community response to noise" refers to the average evaluation of the noise situation by a "community" or group of residents, combined in a single outcome, annoyance. Annoyance may result from noise-induced disturbance of activities, communication, concentration, rest, or sleep, and may be accompanied by negative feelings such as anger or displeasure. It is the most prevalent adverse effect of noise and has been estimated to contribute largely to the burden of disease by environmental noise.[182] To facilitate interstudy comparisons and data pooling for the development of exposure-response relationships, the community response team have proposed standardized annoyance questions and core information to report.[183,184] The preceding years saw many interesting new directions in annoyance research, several of which were already noted in an earlier review of ongoing research into the community response to noise:[185] Cross-cultural comparisons and studies performed in developing countries, studies trying to explain differences between surveys or respondents in annoyance at a given noise exposure, studies investigating ameliorating effects of a quiet façade or insulation measures, studies on the effect of combined exposures or specific exposures such as railway vibration or wind turbine noise, and studies investigating the effects of the soundscape in outdoor settings. A short overview is presented below of recent research findings on noise annoyance published in peer-reviewed journals in the past 3 years (2011 to present).

Monitoring the prevalence of annoyance

Studies were reported that monitor the prevalence of annoyance in populations exposed to (mostly) transportation noise in many non-Western countries, including Eastern European countries,[186] Dubai,[187] Egypt,[188] India,[189] China,[190] and Vietnam.[191,192] One German study on the annoyance response in children reported a lower prevalence of annoyance compared to the regularly reported representative data on adults.[193] Also, research was done on the methodology of monitoring community response to noise, that is, the influence of annoyance question wording or context,[194,195] the usefulness of noise complaints in predicting the prevalence of annoyance,[196,197] and the use of annoyance as a reaction measure indicative of adverse noise exposure or potential health effects.[198-200] Furthermore, some studies were aimed toward a better understanding of the essence of annoyance, exploring its relation to specific disturbances[201-204] to personal factors such as noise sensitivity, negative attitudes, and residential satisfaction,[205-208] and even to electroencephalogram (EEG) variations.[209]

Exposure-response relationships

One of the main objectives of research into the community noise response has been to derive exposure-response relationships. Previously, based on a large international dataset, separate exposure-response curves were derived for aircraft, road traffic, and railway noise.[210] At a given noise level, more annoyance by aircraft noise was found than by road traffic noise (aircraft penalty) and less annoyance by railway noise than by road traffic noise (railway bonus). These relationships are reflected in a EU position paper[211] that has guided EU noise policy. However, there are indications that the annoyance response to aircraft noise has increased over the years,[212] which stresses the need for an update based on more recent studies with standardized methods, and possibly for an increase in aircraft penalty. In addition, the railway bonus is not always observed: Particularly, it does not seem to apply to Asian countries. In a recent survey conducted in Vietnam,[213] no systematic difference was found in exposure-response relationships between railway and road traffic noise, which is consistent with previous research conducted in Korea and Japan. In fact the annoyance response to aircraft noise in Vietnam[191] was even found to be slightly lower than that indicated by the curve in the EU position paper. These recent Asian studies underscore the notion that community response to noise depends on nonacoustical factors such as the cultural and social context as well as on the acoustical factors. To better capture differences in annoyance response between communities, a new methodology was introduced to derive exposure-response relationships.[168,214-216] Instead of statistically fitting the curve to the data, this method makes the strong assumption that the annoyance curve should closely resemble the loudness function, while differences between surveys are expressed in a decibel-equivalent shift named the "community tolerance level (CTL)". The CTL can be used to express differences in "tolerance" to noise between communities, study, or site characteristics, but also between sources. Using this method, average exposure-response relationships for aircraft noise and road traffic noise were found that largely resemble the curves in the EU position paper. However, the prevalence of annoyance due to railway noise was found to differ between sites with and without high levels of vibration and/or rattle,[215] with a railway bonus applying only to the latter. This is consistent with results from a Swedish railway study reporting higher noise annoyance at a given exposure level when noise was accompanied by vibration.[217] Still, this study found even higher annoyance in a situation with a very large number of trains, suggesting that there may be more circumstances in which the railway bonus does not apply.

The benefit of quietness, natural areas and insulation

The exposure-response relationships referred to above have mostly been derived based on the estimated noise levels at the most exposed façade of the dwelling. However, given a certain façade level, several situational characteristics may ameliorate (or worsen) the effects of noise. For instance, residents may have good insulation or a quiet side to their dwelling, or they may have access to quietness or natural areas in their neighborhood. One intervention study in Norway[218] demonstrated that the effect of reducing indoor noise levels by insulation was close to the expected effect of a similar reduction in outdoor levels as predicted from exposure-response curves. Furthermore, studies have been done to quantify the potential benefit of having a quiet side to the dwelling,[163,219,220] and other studies have demonstrated the additional effects of neighborhood noise[221,222] and of views on greenery or on the sea.[223] The importance of visual factors is further supported by laboratory studies showing the positive effects of natural landscape features and transparent barriers on the annoyance due to railway noise.[224,225]

Combined exposure

Residents in an urban environment will usually be exposed to multiple sources of noise, which complicates the use of exposure-response relationships for separate sources. A variety of models to evaluate the effects of combined exposures have been proposed over the years.[226] Some recent studies have tested the validity of models in real-life conditions. Results from surveys near airports in Vietnam where road traffic noise was the dominant source suggest that the annoyance due to the dominant source is the best predictor of the total annoyance. However, a study in China[190] with combined road traffic and railway noise showed that, at high exposure levels, total annoyance was higher for combined exposure than for the same exposure coming from an individual source, which does not agree with the dominant source model. A field study in France[227,228] with combined road and industrial noise concluded that the dominant source model may apply when one source is clearly more annoying than the other, whereas a model for annoyance integration[229] may apply when sources induce approximately equal annoyance. Also, total annoyance caused by combined noise and vibration from high-speed trains simulated in a laboratory setting[230] was much larger than the annoyance caused by noise alone, with both the maximum and the integration of single-source annoyance ratings providing useful predictions of the total annoyance. A field study in Sweden confirmed that higher annoyance is induced by railway noise accompanied by vibration.[217] Increasing attention is raised by the study of the community response to vibration, adopting an approach very similar to noise research.[231,232]

Wind turbine noise

Wind turbine noise has emerged as an important source of annoyance, and several socioacoustic surveys and experimental studies were carried out to evaluate the community response to wind turbine noise, or to figure out which variables influence the annoyance by wind turbines. A survey among residents living in the vicinity of wind turbines in the Netherlands[171] found that self-reported annoyance was higher with higher wind turbine sound emission levels, and an exposure-response relationship was derived. Noise annoyance was also found to be an indicator for effects such as sleep disturbance and psychological distress. In addition, respondents living in areas with other background sounds were less affected than respondents in otherwise quiet areas. In a meta-analysis,[233] the data of the survey in the Netherlands were pooled with two surveys in Sweden. The resulting exposure-response relationships were expressed as the expected percentage of (highly) annoyed residents at a certain L_{den} level, allowing for the comparison to relationships for other sources. This comparison showed a higher annoyance response to wind turbine noise than to other sources at the same equivalent level. Results from these surveys were used to predict the impact of planned wind turbines in the Netherlands[234] and of future wind farms in Canada.[235] Recent Korean laboratory studies found that annoyance is particularly caused by the "swishing sound" and is associated with both the equivalent sound level and the amplitude modulation of the aerodynamic noise from wind turbine blades.[236] The authors suggest that the maximum noise level can be used as a predictor of the annoyance response to wind turbine noise.[237] Other results from a laboratory study[238] show that masking may reduce the perceived loudness as well as annoyance of wind turbine noise, suggesting that positive natural sounds may be used as a noise control measure. Another laboratory study[239] found that recognizing noise as coming from a wind turbine heightens the chance of annoyance, even when the noise is partly masked by traffic noise. Further, attitudinal and personality factors such as noise sensitivity were shown to be related to the annoyance reported.[171,240]

Outdoor noise and soundscape

In addition to the annoyance due to transportation noise in the home setting, some studies have reported effects of the soundscape in outdoor settings. For instance, exposure-response relationships were derived for both annoyance and interference with the experience of natural quiet due to aircraft overflights in several US national parks.[241] Also, the annoyance induced by scooters and motorbikes in urban streets and parks was explored.[242] It was found, additionally, in a laboratory situation that aircraft noise — in particular, helicopter noise — led to annoyance, and affected solitude and tranquility in comparison to natural sounds in subjects watching virtual national park scenes.[243] The observed effects of outdoor noise on annoyance and perceived tranquility suggest that noise has consequences for the potential restorative quality of outdoor settings.

Future research needs

Survey differences in annoyance response and their potential reasons should be addressed to in order to better predict the response in specific situations. Also, more studies are needed on cross-cultural comparisons and the community response to noise in developing countries. Furthermore, effects beyond that of the exposure at the most exposed façade may be quantified to provide information on possible mitigation measures. Not much is known yet about the effects to be expected of interventions, including insulation or sudden changes in noise levels. Further information is also needed on the annoyance response to multiple noise sources and to combined noise and vibration. Finally, relatively little is known about response to outdoor noise and the positive aspects of the environmental soundscape.

Interactions with Other Agents and Contextual Factors

Team 8's work focuses on the effects of noise in interaction with other agents.* The word "agent" was chosen to exclude noise-noise interactions such as the effects of noise from, for instance, industrial and transportation sources, unless these are part of a broader workplace or environmental assessment. Two main research arenas are the workplace and the community setting. Commuters and intercity rail travellers are regularly exposed to crowding, thermal stress, noise, vehicular air pollution, odorants, and vibration. Pilots, vehicle drivers, and persons employed by the transport and logistics industry are often have multiple exposures.

Leroux and Klaeboe[244] provide a brief overview of research presented at ICBEN 2011. An overview of research on combined effects in a residential setting is given by Lercher.[245] Reviews of research on combined effects of noise and chemicals are provided by Campo *et al*.[246] and by Vyskocil *et al*.[247]

A potential alternative to the concept of ambient stressors is given by Lercher *et al*. and by de Coensel *et al*.[248,249] Events caused by different exposures, different sources, different settings, and different circumstances could give rise to similar cognitive and physiological microreactions.

*Increasing interest in the relative importance of different exposures has led to an increase in studies of combined agents, and interest in potential interactions. There is, consequently, some overlap in the papers reviewed by other ICBEN teams and Team 8.

Noise and vibrations

Waye[250] provides an overview of the effects of noise and low-frequency noise and vibrations. Gidlöf-Gunnarsson *et al*.[217] concluded that a 5-7 dB-lower noise level is needed in areas where the railway traffic causes strong groundborne vibrations and in areas with a very large number of trains.

Zhai *et al*.[251] report that high-speed rail passengers and crew feel more comfortable at 200 km/h than 250 km/h, which may be related to the rapid variation of wind speed and noise when passing through tunnels at high speed.

Lee and Griffin[230] investigated noise and vibration on annoyance in buildings during the passage of a nearby high-speed train. Vibration did not influence the ratings of noise annoyance, but total annoyance caused by combined noise and vibration was considerably greater than the annoyance caused by noise alone. Noise annoyance and total annoyance caused by combined noise and vibration were associated with subject self-ratings of noise sensitivity. Smith *et al*.[252] measured cardiac accelerations using a combination of polysomnography and ECG recordings. Sleep was assessed using questionnaires. With increasing vibration amplitude, they found a decrease in latency, an increase in amplitude of heart rate, a reduction in sleep quality, and an increase in sleep disturbance. Huang and Griffin[253] report that higher-magnitude vibrations appeared to mask the discomfort caused by low levels of noise. When judging vibration, higher level of noise appeared to mask the discomfort caused by low magnitudes of vibration. Vibration discomfort was more influenced by noise than noise discomfort was influenced by vibration.

In the work setting, Pettersson *et al*.[254] conducted a longitudinal study from 1987 to 2008 on 189 male workers from a heavy engineering production workshop (paper and pulp-mill machinery). These workers were exposed to noise [1987: 76 dB(A); 2008: 79 dB(A)] and vibrations generated by handheld tools, mainly grinders (1987: 11.0 m/s^2; 2008: 7.6 m/s^2) and hammers (1987: 5.8 m/s^2; 2008: 4.5 m/s^2). The results show that hearing loss is significantly associated with the cumulative lifetime of exposure to hand-arm vibrations (OR: 1.12; 95% CI: 1.02-1.23). The authors also showed that the risk of hearing loss increases from 0 to 4840 h of exposure and then decreases above this value, suggesting an association between the risk of hearing loss and combined exposure to noise and hand-arm vibrations.

Noise and solvents

Hughes and Hunting[255] conducted a retrospective cohort study (n = 503) on military and civilian workers exposed to noise (<85; ≥85 dB(A)-8h) and a mixture of organic solvents (toluene, xylene, styrene, benzene, and JP-8 jet fuel). Noise exposure was based on workstation measurement, whereas solvents exposure was estimated from chemical sampling, survey documents, and purchase records (all inferior to American established exposure limits). Apart from significant associations between hearing loss, age, duration of follow-up (mean of 3.2 years), and noise exposure, no other association or interaction with noise could be made with solvent exposure. In contrast, positive results were reported by Metwally *et al*.[256] in a cross-sectional study on paint plant workers (n = 222) exposed to noise alone (68.2 to 87.1 dB(A)-8h) or to noise and a mixture of solvents (toluene, xylene, acetone, butanol, isopropanolol, ethanol; all inferior to established Egyptian exposure limits). Both noise and solvent exposure were based on workstation measurements. A significantly higher prevalence of sensorineural hearing loss was observed in workers exposed to both noise and solvents compared to those only exposed to noise, even if the former group was exposed for a shorter time period (16.38 ± 9.44 years vs 24.53 ± 9.59 years). In the largest cross-sectional study available, Morata *et al*.[257] examined workers (n = 862) exposed to styrene alone or to noise (80 to 84 dB (A)-8 h) and styrene (7 ± 10 to 68 ± 61 mg/m^3). Both noise and solvent exposure were based on workstation measurements. No significant effect of noise on hearing (OR: 1.01; 95% CI: 0.99-1.03) was observed for those low levels of noise exposure except when in combination with styrene (OR: 1.0055; 95% CI: 1.0009-1.0102).

Noise and smoking

Tao *et al*.[258] conducted a cross-sectional study on 517 males working at a car manufacturing plant in China. These workers were noise-exposed at work (91.02 ± 6.12 dB(A)-8h) and were categorized as nonsmoker or smoker. A multivariable binary logistic regression analysis revealed that workers who smoked were 1.94 times more likely to have a high frequency hearing loss (3, 4 and 6 kHz) than did nonsmokers (95% CI: 1.31-2.88). When adjusted for age, the result did not change significantly (OR: 2.23; 95% CI = 1.46-3.39). In a nice complement to Tao and colleagues' work, Ferrite *et al*.[259] examined a sample of 1723 women among which occupational noise exposure was reported by 364 women and cigarette smoking by 320 women. Information on hearing status as well as all data included in this study were collected using a questionnaire. After adjustment for age, job type, solvent exposure, and high blood pressure, the prevalence ratio of hearing loss was significantly greater in women who declared smoking (PR: 1.39; 95% CI: 1.07-1.81) and in women exposed to noise (PR: 2.66; 95% CI: 1.86-3.82). The prevalence ratio of hearing loss for those who smoked and were noise-exposed was even greater (PR: 3.94; 95% CI: 2.81-5.52), but failed to reach statistical significance under the additive model assumption.

Noise and air pollution

The European Network on Noise and Health (ENNAH)[260] provided a recent review on the health effects of noise and air pollution. Recommendations from the network are summarized in a paper by Stansfeld and Clark.[261]

Cardiovascular effects

A recurring theme is the need for proper exposure assessment. Tetreault *et al*.[76] concluded that "confounding of cardiovascular effects by noise or air pollutants is low, though with further improvements in exposure assessment, the situation may change." In a review of Austrian research, Lercher *et al*.[262] found that "air pollution has not played a relevant role as a moderator in the noise-hypertension or the noise-angina pectoris relationship." Assessment of noise exposure is critical.

Eriksson *et al*.[93] reported that neither traffic load nor road traffic noise is associated with self-reported cardiovascular outcomes (roadside study). Lercher *et al*.[74] reported that children with premature births and elevated chronic stress (i.e., elevated overnight cortisol) were more susceptible to adverse blood pressure responses to road traffic noise. NO_2 had no influence. The authors argued for a contextualized soundscape perspective.

Gan *et al*.[78] reported that elevations in noise and black carbon were associated with 6% and 4% increases, respectively, in CHD mortality, and suggested that there are independent effects of traffic-related noise and air pollution on CHD mortality.

Selander *et al*.[110] concluded that a combination of noise exposure and job strain substantially increases the risk of MI.

Mortality risk per μg/m^3 black carbon could be substantially higher than for $PM_{2.5}$.[263] A review on black carbon was written by Janssen *et al*.[264]

Microsituational approaches to exposure assessment

Dons *et al*.[265] found that 6% of the time spent in transport accounts for 21% of personal exposure to black carbon and approximately 30% of inhaled dose. Concentrations in transport were 2-5 times higher than concentrations encountered at home. Steinle *et al*.[266] reviewed modern approaches for spatiotemporal personal exposure assessment.

Cognitive effects

Clark *et al*.[267] reported that moderate air pollution exposure levels at school were not associated with a range of cognitive and health outcomes.

Noise and air pollution annoyance, life quality, and self-rated health

With respect to perceived air pollution, there are no standard questions on perceived air quality. Deguen *et al*.[268] used psychometric methods to construct a scale to assess risk perception and air pollution as a nuisance.

Honold *et al*.[269] found that self-rated health and neighborhood satisfaction could be predicted from multiple stressors and resources, while more general health symptoms were related only to perceived air pollution. Riedel *et al*.[124] considered noise annoyance within the context of neighborhood satisfaction as a mediator between exposures and self-reported health.

Claeson *et al*.[270] reported that perceived pollution and health risk perception (rather than exposure) induce annoyance and health symptoms in odorous environments. In one of a few longitudinal studies, Axelsson[271] found that annoyance caused by industrial odor, industrial noise, and worries was less in 1998 and 2006 than in 1992, while industrial noise annoyance increased significantly over time. The prevalence of worry remained constant.

Soundscape, positive environments, and aesthetics

Environments and soundscapes promoting health are described in several studies.[272-274] Lee[275] reviewed the potential health benefits of green areas.

Yang[276] found significant asymmetry in the EEG activity between the vegetation scene and traffic scene groups, indicating that landscape plants can moderate or buffer the effects of noise. Lee *et al*.[224] concluded that visual images significantly influenced noise perception.

Future research should use more specific exposure indicators (e.g., black carbon), and refine noise exposure indicators by adjusting for context. Standardized questions on air pollution, odors, and perceived health risk are also needed. Matching physiological and psychological reactions in real time against spatiotemporal exposure indicators is a promising new research paradigm. In the work setting, research should aim at establishing dose-effect curves, at least for the chemicals for which evidence for interaction with noise is more convincing (e.g., styrene).

Noise Policy and Economics

Introduction

Urbanization and the associated growth in population mobility have resulted in the intensification of environmental noise, particularly in densely populated areas. Many developed, mainly Western, countries and individual cities are now taking actions to enhance their institutional and technical capabilities to monitor and control noise exposure and implement preventive actions to reduce the risks that environmental noise poses to their citizens. ICBEN Team 9, Noise Policy and Economics, provides an update on international progress in noise mitigation policies and strategies, best practices, and guidelines for environmental noise management for ICBEN 2014. This review focuses on developments in evidence and policy by international bodies and in selected countries.

International bodies

In November 2012, the International Institute of Noise Control Engineering (I-INCE) published a report of its Technical Study Group 1 on outdoor recreational noise.[277] "Recreational noise" is defined as the noise produced by recreational activities involving aircraft, on-road and off-road vehicles, and watercraft. Recreational activities include pastimes undertaken to relax or refresh spirit and strength. "The aim of this report is to increase awareness of the effects of recreational noise and to suggest strategies that may be used to ameliorate the situation prevalent in many countries today"[277] (cf. page 2). The aim was also to provide practical advice on noise reduction from major motor sport activities and street racing, which are an issue in some but not all countries. The report recommends the adoption of the WHO environmental noise recommendations for residential and noise-sensitive areas.

The European Environment Agency (EEA) published a handbook[278] in 2012 on the delivery of data in accordance with Directive 2002/49/EC (END), including updates to ensure compatibility with the Reportnet system for data delivery.[279] Annexes provide specific guidance for major roads, railways, airports, and agglomerations; strategic noise maps, action plans, and data collection; noise limit values and noise control programs. Data for 2007-2012 are available in the Non-Occupational Incidents, Situations and Events (NOISE) database.[280]

In 2013 the Final Report of ENNAH was published.[260] The Network aimed to support research-based policy making. It examined a range of issues including how to do the following:

- Make current noise maps more useful for public health research;
- Develop innovative exposure measurement techniques in future noise and health studies;
- Jointly study air pollution and noise;
- Establish research partnerships among young and older noise and health researchers;
- Improve estimates of the burden of disease from exposure to environmental noise; and
- Develop skills in health impact assessment for transport-related noise exposure.
- ENNAH has outlined recommendations for research to strengthen the evidence base on the following:

- Exposure-response relationships for hypertension and CHD related to environmental noise by using robust study designs;
- The associations between environmental noise and children's cognitive abilities;
- Establishing whether interventions to reduce environmental noise do reduce its impact on health; and
- Assessing where new investment in noise research should be placed.

European Commission (EC) initiatives are mostly addressing issues related to END. Preliminary estimates of the burden of disease due to noise exposure indicate that at least 1.685 million DALYs are lost annually in EUR-A†, mostly due to traffic noise. This number is comparable to the estimated 2.651 million DALYs lost due to the exposure of people to airborne particles of diameter less than 2.5 μm ($PM_{2.5}$) in the same region.[281,282] Note that 1.685 million DALYs correspond to approximately 0.35% of Gross Domestic Product.[2] In 2011, the EC published a report on the implementation of the EU's environmental noise policy and organized an online consultation on the report in 2012.[283,284] The consultation gathered stakeholders' views on the information provided in the report, and the effectiveness, strength, and weaknesses of EU environmental noise policies.

In 2013, the Committee on Aviation Environmental Protection (CAEP) of the International Civil Aviation Organization (ICAO) agreed on a new noise standard 7 EPNdB‡ (Effective Perceived Noise level) below ICAO's current (Annex 16, Volume 1 Chapter 4) noise limit for new-design and for in-use lighter aircraft.[285] CAEP also agreed to a lower noise limit for subsonic jet airplanes with takeoff mass below 8.618 tons, and to a new noise standard for tiltrotor aircraft (same as that existing for helicopters). In addition, CAEP developed medium- and long-term goals to reduce noise from turboprop, turbofan, and new-design aircraft.

Activities in countries

The UK Department for Environment, Food and Rural Affairs (DEFRA) commissioned a project in 2012 that examined the effectiveness of a number of noise policy measures introduced since 1960 in reducing the impact of the noise problem that they were intended to address.[286] This was to inform the delivery of the Noise Policy Statement for England (NPSE), which applies to three categories of noise: Environmental noise (i.e., from transport), neighbor noise (i.e., from occupiers of houses and flats), and neighborhood noise (e.g., from premises used for industrial or leisure purposes).[287] Measures examined were: Aircraft and road vehicle noise emission limits; building regulations relating to sound insulation; noise nuisance and control legislation; and controls on construction noise.

With respect to aircraft noise, the study found that the physical area with the 57 dB(A) $L_{eq,16h}$ contour had reduced by 87% (Heathrow) and 78% (Gatwick) between 1972 and 2009 despite growth in aircraft movements. For other airports where data were only available for later years, the reductions were smaller, as would be expected. Although the analysis could not allow for other airport-specific factors, the magnitude of the change is remarkable. Road traffic noise was found to have fallen by 2 dB(A) on motorways and by 5 dB(A) for A roads and minor roads between 1971 and 2010 despite high traffic growth, especially on motorways. In other areas, the data were less amenable to assessing effects. However, compliance with building regulations has increased. Although statutory noise nuisances have increased over time, it is likely that the legislation has enabled intervention and resolution that would not otherwise have occurred.

Based on the information from noise mapping, DEFRA developed and published in 2013 and 2014 a number of noise action plan publications, including:

- Noise Action Plan (NAP): Agglomerations;[288,289]
- NAP: Roads (including major roads) Environmental Noise (England) Regulations 2006 (as amended) 2014;[290]
- NAP for railways (including major railways);[291]
- Implementation of round 1 action plans: Progress report;[292]
- Guidance for airport operators to produce noise action plans;[293] and
- Consultation: Draft noise action plans.[294]

Each NAP is structured in several parts. The introductions to the NAPs for agglomeration noise,[288] road traffic noise,[290] and railway noise[291] all cover the following: The legal and policy context; and the scope, implementation, monitoring, and review of the NAP. The NAP for agglomerations goes on to present the approach to noise management in the 65 agglomerations covered, including a summary of the results of noise mapping, and an evaluation of the number of people exposed to road traffic, railway, industrial, and aircraft noise. Around 7.4 million people in the agglomerations are exposed to road traffic noise in excess of 55 L_{den}, and 1 million to similar levels of railway noise.

The important issue of quiet areas (QAs) is addressed in this NAP. The NAP covers: Policy and legal requirements for the protection of QAs, the identification of QAs, the expected characteristics of quiet or relative quiet and associated benefits; and their management and consultation.

†EUR-A comprises the countries: Andorra, Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marina, Slovenia, Spain, Switzerland, and the United Kingdom.

‡The EPNdB is a measure of human annoyance due to aircraft noise, taking into account the perceived noise level and duration. It is EPNdB = dB(A) + 13

The NAP also has a useful appendix specifying QAs according to the END in terms of: The criteria for QAs; the process of identifying QAs; the characteristics of spaces nominated as QAs; the measures to preserve QAs; and a draft application form to propose a space as a QA.

The NAPs for roads/railways both cover the same set of issues. The approach to managing road/rail noise is briefly summarized as including the following: Control at source; planning controls; compensation and insulation; maintenance; and any specific initiatives as identified under the END (more detail is provided in an appendix). Noise mapping results are presented, and the NAP process is outlined in terms of the following: Identifying important areas; noise reduction measures already in force; implementation; liaison with relevant local authorities and the public; reporting and consultation; and implementation and monitoring. The long-term strategy regarding the management of road/railway noise is also discussed, and processes for information and formal public consultation are provided.

In 2011, DEFRA published a report titled "The Economic Value of Quiet Areas,"[295] as requested by the END and the Natural Environment White Paper.[296] Using a willingness-to-pay approach, initial estimates for the total use value for visits to QAs for England as a whole lie somewhere between £19.02 million and £1.4 billion per year. Since the publication in 2011, DEFRA has also published periodic Natural Environment White Paper implementation update newsletters.[297] The newsletters highlight significant progress since the last update.

In 2011 DEFRA asked the Transport Research Laboratory to prepare a report on the effects of environmental noise on productivity.[298] The report was not able to quantify the economic impacts of environmental noise on productivity. In contrast, the economic impacts of environmental noise on health in England amount to £7-10 billion annually.

In the same year, DEFRA also published a report on the monetary quantification of selected environmental noise-related health impacts.[299] The Quality Adjusted Life Years (QUALYs) lost to acute MI, stroke, and dementia due to road noise exposure in agglomerations containing 43% of the population were valued at £1.1 billion annually; those due to railway noise levels amounted to £43 million annually.

In 2012, the US Department of Transport (US DoT) published the *High-Speed Ground Transportation Noise and Vibration Impact Assessment*.[300] This document provides guidance and indicates procedures for the assessment of potential noise and vibration impacts and mitigation measures resulting from proposed high-speed ground transportation (HSGT) projects with train speeds of 90-250 mph.

In 2013, the US National Academies Press published a document on the protection of National Parks soundscapes, based on a meeting held in 2012,[301] which focused on the scope for reducing operational noise within parks. Cost-effective options identified included the following: Monitoring noise levels; raising staff awareness; better maintenance; and purchasing practice. The results of the workshop were more qualitative than quantitative.

The Swiss Federal Office for the Environment (FOEN; BAFU) asked a team of scientists to develop a model to simulate noise levels along the Swiss rail network.[302,303] The model is intended to help federal agencies to calculate the sound exposure around existing and planned railway lines at individual buildings and to identify the most effective remedial measures using a holistic approach.

As discussed in the ICBEN 2011 Review,[304] the most important national standards relating to environmental noise control developed by the South African Bureau of Standards (SABS) are the SANS 10103, SANS 10117, SANS 10181, SANS 10210, SANS 10281, and SANS 10328 (SANS = South Africa National Standard). In 2012, further standards were developed, based on the corresponding ISO standards. These new standards refer to the following:

- A framework for calculating a distribution of sound exposure levels for environmental noise assessment;[305]
- Determination of sound power levels and sound energy levels — survey[306] and engineering methods;[307,308]
- Mechanical vibration and shock — evaluation of human exposure,[309-311] and guidelines for the measurement of vibrations on structures.[312]

The following important documents have been published recently in Australia:

- The Noise Environment Protection Policy;[313]
- The New South Wales (NSW) Road Noise Policy;[314]
- A NSW guidance document for better management of railway noise;[315]
- A Western Australia Environmental Protection Agency report and recommendations relating to noise from electrical distribution transformers;[316] and
- A review involving all relevant stakeholders of the Australian standard AS 2021-2000 relating to aircraft noise.[317,318]

Future research needs

It is clear that research is still needed to:

- Refine estimation procedures for estimating the impact of environmental noise on health and well-being;
- Assess the scale of the noise problem in cities and identify cost-effective mitigation measures;
- Identify the impacts of policy measures on noise levels, and hence on health and well-being; and
- Estimate the economic costs of environmental noise and the benefits of reducing noise exposure.

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